NEW JUPITER SATELLITES AND MOON-MOON COLLISIONS

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We report the discovery of 12 satellites of Jupiter, giving Jupiter 79 known satellites. They are between 23rd-24th mag in the r-band and 1-3 km assuming dark albedos. Most were discovered using DECam on the Blanco 4m telescope in March 2017 during a continuation of the outer solar system survey detailed in Sheppard & Trujillo (2016) and Sheppard et al. (2016). Recoveries were obtained at the Magellan, Discovery Channel, Subaru and Gemini telescopes. S. Sheppard maintains a webpage showing the characteristics of the moons.

Nine of the discoveries are in the distant retrograde groupings (Fig 1). The retrogrades are clustered into orbital groupings that might be the remnants of once-larger parent bodies that fragmented from collisions with asteroids, comets, or other satellites (Sheppard & Jewitt (2003), Nesvorný et al. (2004), Jewitt & Haghighipour (2007), Nicholson et al. (2008), Bottke et al. (2010), Nesvorný et al. (2014)). Three are in the compact Carme group (S/2017 J5, S/2017 J8 and S/2017 J2). Four are in the more diffuse Ananke group (S/2017 J7, S/2016 J1, S/2017 J3 and S/2017 J9), where Euporie is somewhat disconnected. Two are in the Pasiphae group (S/2017 J6 and S/2017 J1), which is the most dispersed grouping, with S/2017 J6 having the largest eccentricity, 0.557, and aphelion at 0.66 Hill radii. Jupiter LVIII (S/2003 J15) is somewhat disconnected from the group with a lower inclination and semi-major axis.

Two are in the closer Himalia prograde group near 28° inclination (S/2017 J4 and S/2018 J1). These were the brightest found around 23rd mag, but were harder to discover and track because they are more in the glare of Jupiter. The Himalia group has a large velocity dispersion (Li & Christou 2018), which we suggest could be explained by a second breakup event after an initial Himalia breakup as most Himalia members don't cluster near Himalia but further away, near Elara and Lysithea.

S/2016 J2, nicknamed Valetudo, has an orbit unlike any other and is the most distant prograde satellite around any planet at 0.36 Hill radii (Sheppard et al. 2018). Numerical simulations show it stable, with average and range of $i = 34.2 \pm 3^{\circ}$, $e = 0.216 \pm 0.125$, and $a = 1.89 \pm 0.07 \times 10^{7}$ km over 10^{8} yrs. Our stability simulations show a S/2016 J2 like orbit would be stable out to $a = 2.18 \times 10^{7}$ km or 0.41 Hill radii, but no further, unlike more distant and eccentric retrograde satellites. S/2016 J2's large semi-major axis means it significantly overlaps the orbits of the distant retrogrades, unlike most inner progrades. Carpo also has significant overlap with the retrogrades, though at a higher inclination, 51°.4, than S/2016 J2 at 34°.0.

The retrogrades are not expected to collide much among themselves (Nesvorný et al. 2003). Using the MERCURY integrator and a particle in a box calculation, we find S/2016 J2 has at best a few percent chance of colliding with a big retrograde (Pasiphae, Ananke, Carme or Sinope) over 4.5 Gyrs. At 1 km, S/2016 J2 would not disrupt the bigger retrogrades, though a head-on impact would be very energetic at several km/s, likely producing several large fragments (Benz & Asphaug 1999). If S/2016 J2 was several times larger in the past, it would be more likely to collide with and fragment a large retrograde satellite. Though not favorable, its possible S/2016 J2 is the biggest remnant of

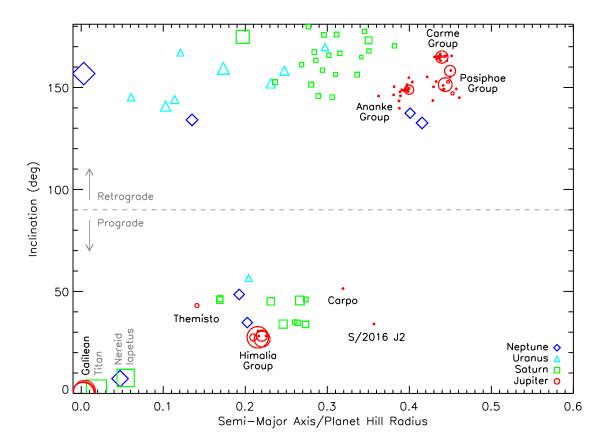


Figure 1. The outer satellites with well determined orbits and large inner satellites. Symbol size represents the Log of the satellite size.

a once-larger satellite that helped form a retrograde cluster through collisions. Prograde Carpo has similar retrograde collision probabilities as S/2016 J2, it being bigger but closer in. Retrograde collisions with Himalia members are also possible (Nesvorný et al. 2003). Though retrograde-prograde moon-moon collisions are unlikely individually, taken together, a retrograde-prograde collision has likely occurred between the outer satellites of Jupiter.

We observed every well known outer satellite of Jupiter in 2017 and 2018 and rediscovered many of the 2003 and 2011 satellites that had poorly determined orbits (Jacobson et al. (2012), Brozović & Jacobson (2017)). We also found many unknown satellites over 24th mag that were too faint to follow and obtain good orbits. Two of these lost satellites appear to be in the Himalia group and the rest retrogrades. Some are likely the faint low quality orbit 2003 satellites yet to be linked. This confirms Sheppard & Jewitt (2003) that Jupiter has about a hundred satellites larger than 1 km.

The smallest satellites in the orbital groups are still abundant and not dispersed towards Jupiter. This suggests the collisions that created them occurred after the era of planet formation as significant gas and dust would preferentially drag the smaller satellites inward (Jewitt & Sheppard 2005).

There are no obvious retrograde satellite groups around the other giant planets, except possibly Neptune (Sheppard et al. 2006). Saturn's progrades show inclination clustering but with less stringent semi-major axis clustering (Gladman et al. (2001), Holt et al. (2018)).

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